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Annual Status Report

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REWETTING OF MONOGROOVE HEAT PIPE IN SPACE STATION RADIATORS

by

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Following is the annual status report for the experimental work in progress regarding the rewetting of a monogroove heat pipe in a micro gravity environment. This report will be divided into two sections. The first details improvements in the experimental apparatus, and the second reports the ground based and theoretical results.

IMPROVEMENT OF EXPERIMENTAL SETUP

Improvements in the test apparatus have proceeded as the need was observed. These have included a new plate material, the addition of thermocouples, an improved heater controller and a position measuring transducer.

MATERIAL

Currently, the apparatus consists of a plate of oxygen free copper, in which the prespecified grooves have been cut. The material was changed to oxygen free copper to ensure repeatability of the experiments.

DATA NODES

There are 30 thermocouples embedded in the bottom of the copper plate for density and redundancy. Figure 1 shows the position of these thermocouples, as well as the dimensions of the plate and the grooves, in inches. The thermocouples are located in two lines along the length of the plate and are connected to the data acquisition system. This system converts the thermocouple voltage outputs into temperature readings in accordance to the thermocouple manufacturer's specifications.

FRONT POSITION & VELOCITY

Linear position of the traveling thermocouple is provided by a LVDT linear position transducer. This is interfaced with the data acquisition system as well, which provides simultaneous position and temperature measurements.

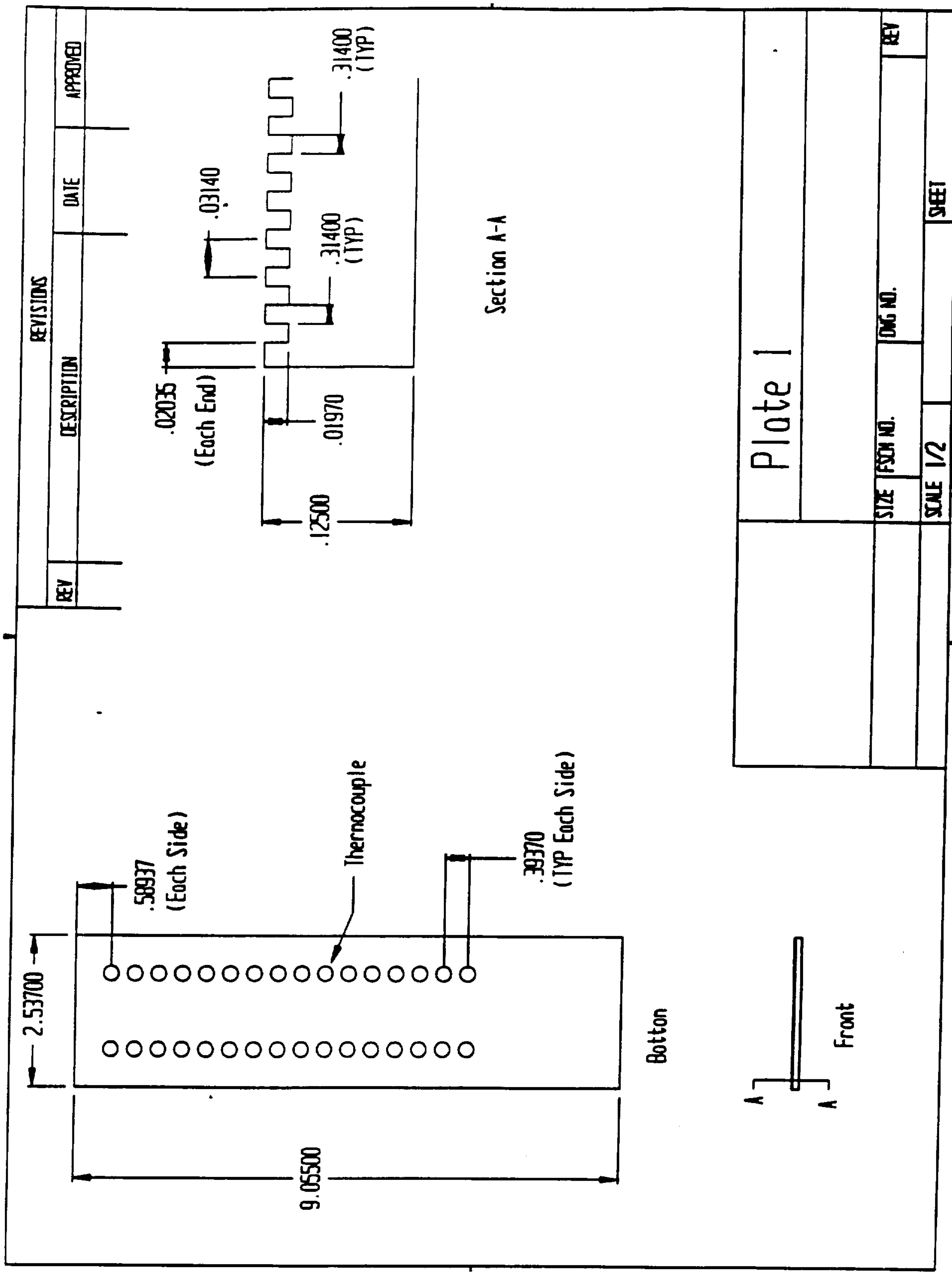


Figure 1

Thermocouple positions and plate dimensions

HEATER CONTROL

Heater control is maintained by a current controlled PID temperature controller. The controller used in earlier experiments was an on/off controller, which caused superfluous spikes in the temperature data. The new controller is capable of maintaining the temperature of the heater constant, within 5% of the set temperature, over the duration of the test run.

DOCUMENTATION

The experiments are being videotaped using an 8 mm video recorder. Video recording the experiment allows the experimenter to observe the motion of the liquid front very accurately, and to manually determine the approximate velocity of the liquid front.

FLUID DELIVERY

Fluid delivery to the plate is currently achieved by filling a reservoir, into which the end of the plate sits, as shown in figure 2. The grooves wick the alcohol up after the liquid in the reservoir reaches the correct height. To ensure that no hydrostatic force pushes the liquid along the plate, a hole was drilled into the side of the reservoir to allow for overflow. Since this method employs gravity as its driving agent, it will need to be modified before airborne tests can to be conducted.

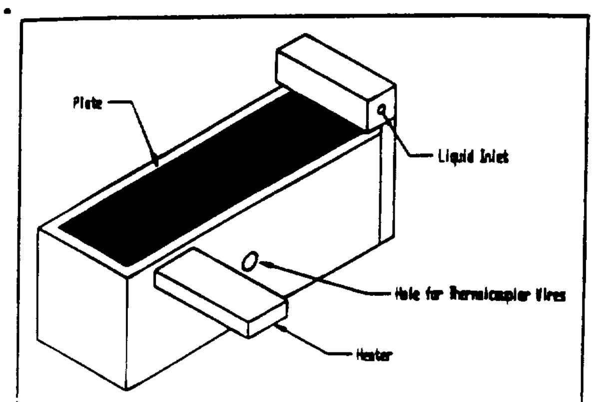


Figure 2
Reservoir location

INVERTED VIDEOTAPING

Videotaping of the experiment while the plate is inverted caused condensation of the alcohol vapor on the camera lens. To alleviate this problem, we are currently working with the university's Material Science Department in the fashioning of an anti-fog lens cap. The lens will be coated with a thin, approximately 400 angstroms, layer of gold which can sustain a current. The current will heat the lens, which will inhibit condensation. A Flourad surfactant (FC-722) is also being considered as a possibility of preventing condensation.

POSITION CONTROL

We are currently analyzing the data from our preliminary ground based tests to aid in designing a position controller for the travelling thermocouple. The concept behind the position controller is to be able to place the travelling thermocouple exactly at the liquid front at all times. If this can be done, the position of the thermocouple will be recorded through the LVDT, and a very accurate velocity profile can be obtained. From the preliminary data, it was found that the liquid front in the different grooves was not at the same distance from the reservoir at any given time, which complicates the design of the controller. The way the controller is currently designed, only a approximate velocity measurement can be made.

GROUND BASED RESULTS

EXPERIMENTAL RESULTS

Many experiments have been performed on the grooved plate in both the face-up and face-down positions. The face-up position refers to the grooves facing upwards, while the face-down position refers to the grooves facing downwards. As was mentioned earlier, both the temperature and velocity were measured for these tests. For each of the two cases, several trials were run at room temperature, 50, 75, 100, 125 and 150 degrees Celsius. Many trials were performed to check the repeatability of the experiment.

Following is the method that is used when the experiment is performed:

- Clean the plate with Acetone
- Position and focus the camera
- Adjust the temperature controller to the desired temperature
- Allow plate to attain isothermal conditions
- Fill the reservoir to just below the bottom of the plate
- Simultaneously start data acquisition system, LVDT, and video camera
- Increase the flow through the rotameter, and allow the alcohol to wick up the grooves
- Stop recording on the camera
- Turn off LVDT and temperature controller
- Clean the plate with Acetone and distilled water

The above procedure was followed for every trial, but after many trials, some oxidation was noticed on the plate. For this reason, an additional cleaning agent is now used to clean the plate. This cleaning agent is named Oakite 33, and contains phosphoric acid, 2-butoxy ethanol, nonylphenoxy polyethoxy ethanol, water, and gluconic acid.

Some typical results of the preliminary experiments can be found in appendix A. These results compare the temperature profiles between the face-up and face-down conditions at heater temperatures of 125 and 150 degrees Celsius. Some of the velocity profiles are also given for various temperatures. It can be seen that there are significant differences between the face-up and face-down trials. The heat transfer rate for the face-down test is greater than that for the face-up test, and their velocities are also different.

The velocities for the higher temperature face-down trials are not given because it is currently not possible to determine them. These velocities cannot be determined because of the condensation that develops on the lens during the experiment. As was stated earlier, several different methods are being considered to prevent this condensation. The velocity profiles are also only crude estimates, especially near the liquid entrance, where the velocity is high. To develop better velocity profiles, a better recording and playback system is being sought.

ANALYTICAL RESULTS

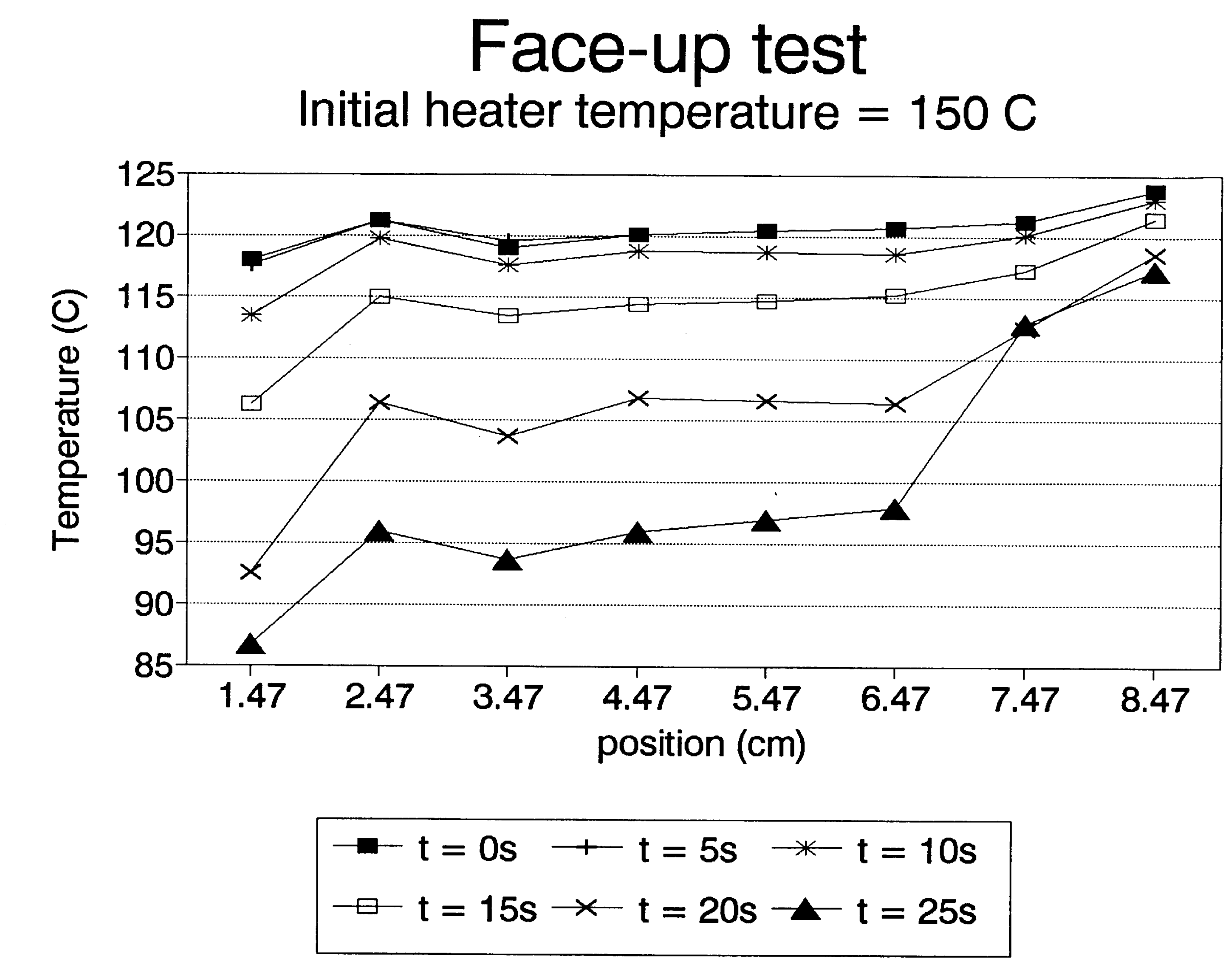
Tien and Yao's [1] approach was used as a rough estimate to calculate the temperature variation with respect to the liquid front. The mean convective boiling heat transfer coefficient of the liquid film is estimated from the pool boiling curve of isopropanol [2]. As a first approximation, $h_s = 5778$ W/(K*m^2) for a smooth plate. To account for the effects of the grooves, a grooved geometric coefficient, N, was introduced [3]. For this case, N = 1.75, which raises the heat transfer coefficient to $h = N*h_s = 1.75*5778 = 10112$ W/(K*m^2). The Biot number was calculated to be much less than one, and the Peclet number was assumed to be less than one. With these two conditions, Tien and Yao's two-dimensional solution reduces to a one-dimensional solution.

Using the one-dimensional solution and the initial temperature profile of the heated plate, the temperature profiles and velocities were calculated for different times. The calculated temperature profile agrees with the experimental temperature profile if the velocity profile is adjusted to that of the experimental velocity profile. This must be done because the calculated velocity profile is about twice that of the measured velocity profile.

FUTURE WORKS

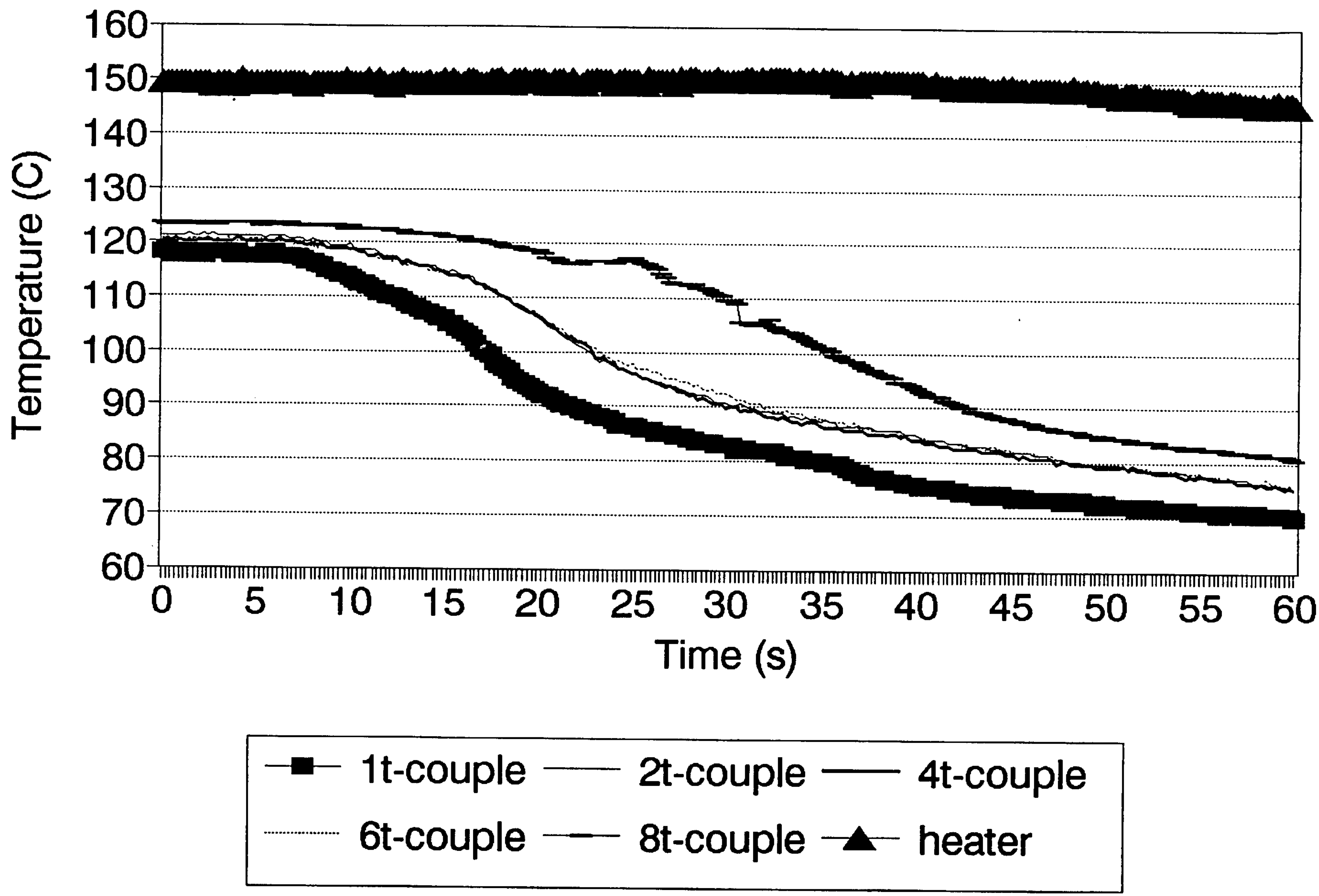
Several aspects of this experiment will be improved upon before flight tests will be conducted. The video recording equipment must be affixed to the rest of the experiment, an appropriate ventilation system must be built, and a method of starting the video recorder and data acquisition simultaneously must be found. New sets of experiments will include a constant heat flux along the entire length of the plate, compared to the constant temperature at one end of the plate that is being used now. Also, once a condensation-free lens cap is made, the face-down trials will be done over to determine the velocity profiles. Finally, if a better recording/playback system is found, all of the velocity profiles will be recalculated.

APPENDIX A

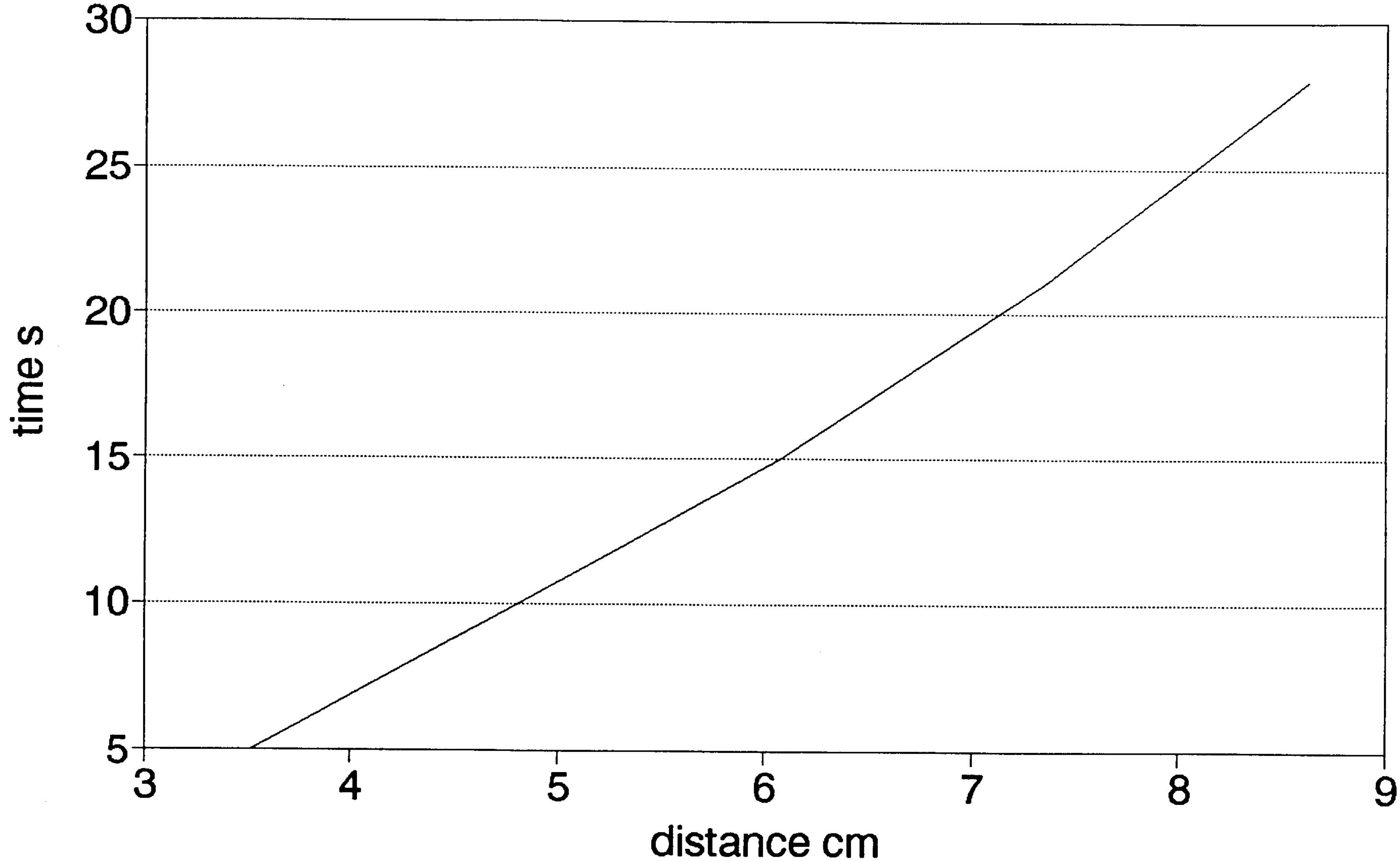

Face-up test
Initial heater temperature = 150 C
Temperature (C)
125
120
115
110
105
100
95
90
85
1.47
2.47
3.47
4.47
5.47
6.47
7.47
8.47
position (cm)
t = 0s
t = 5s
t = 10s
t = 15s
t = 20s
t = 25s

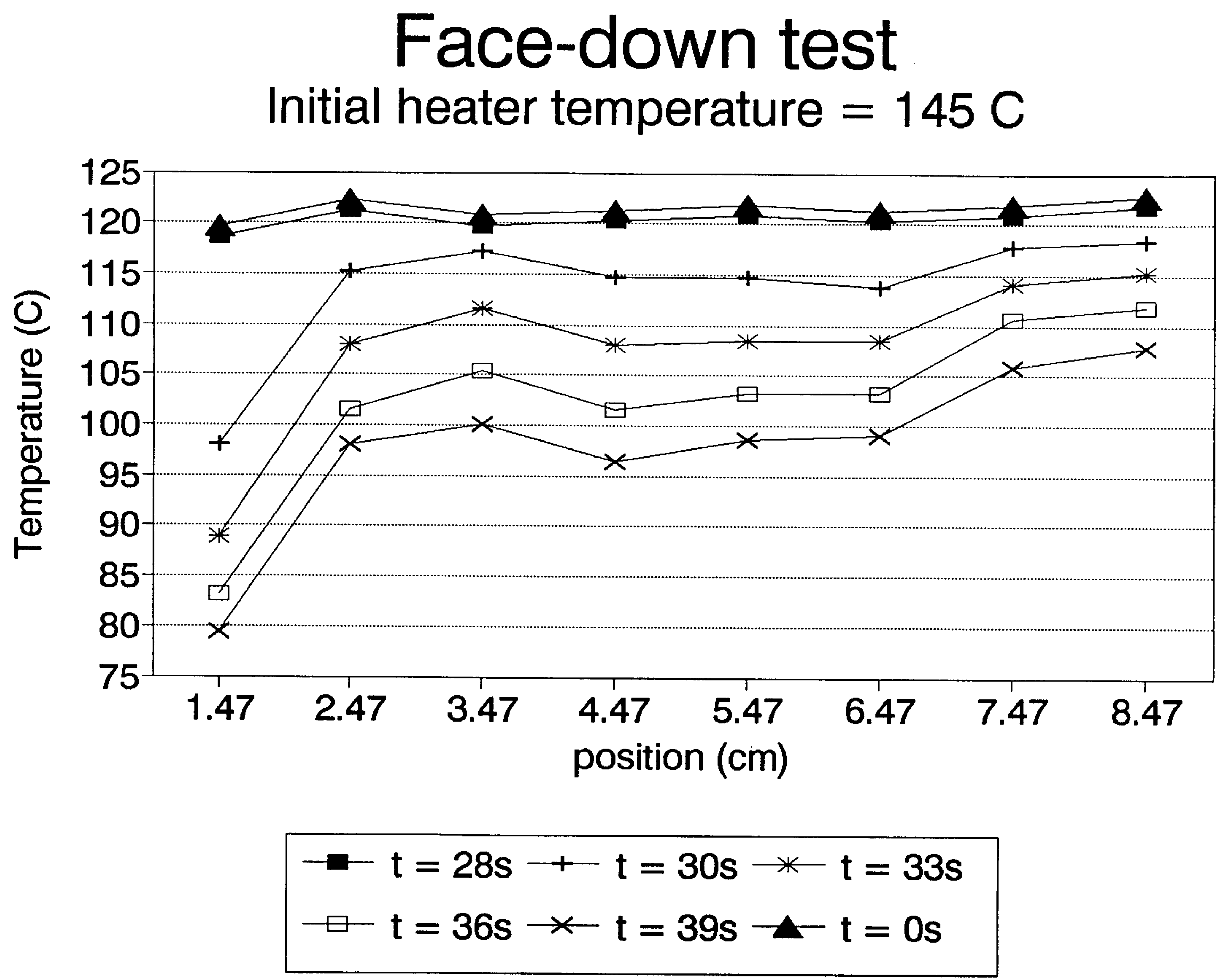
Face-up test

Initial heater temperature = 150 C



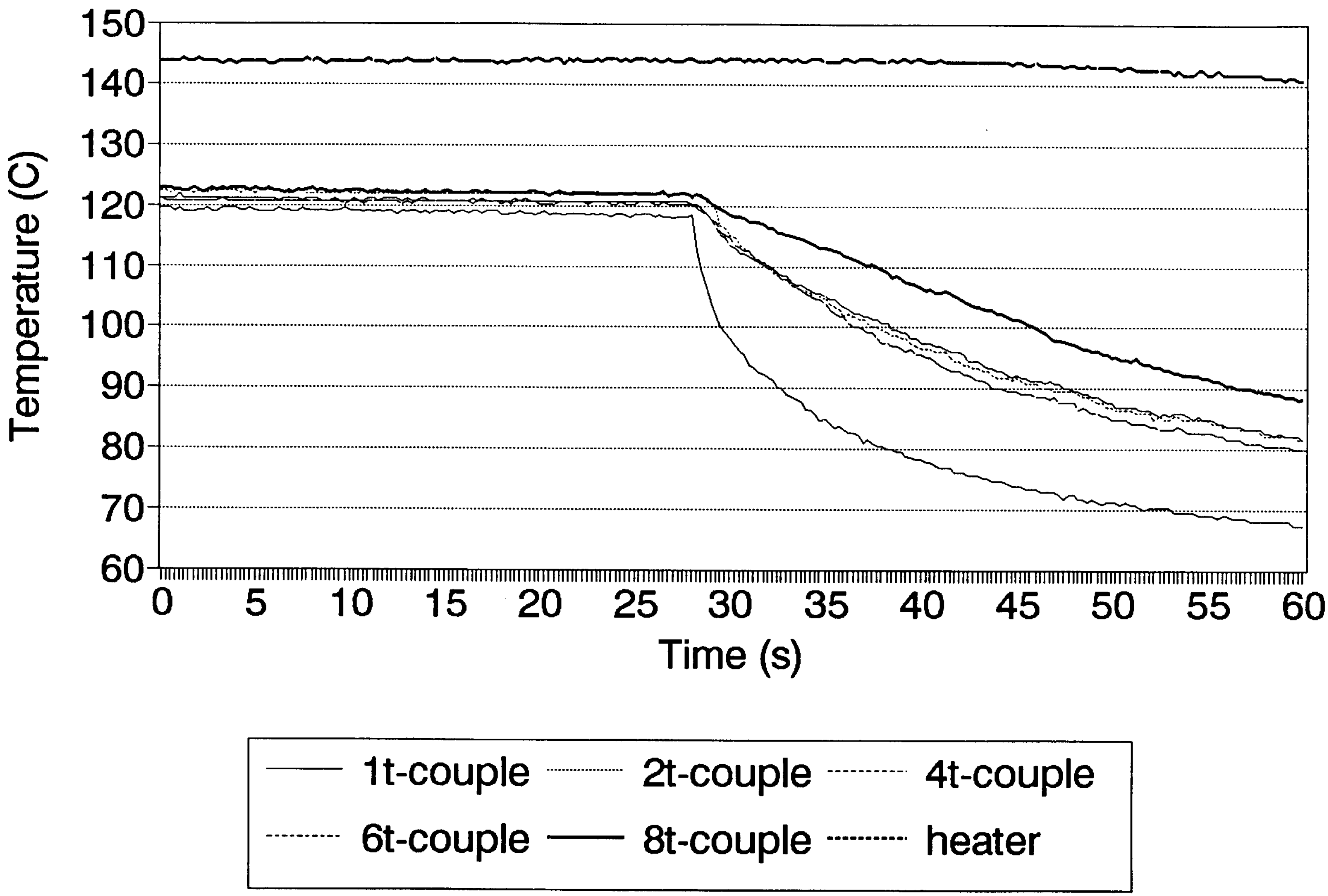
150 C
face-up

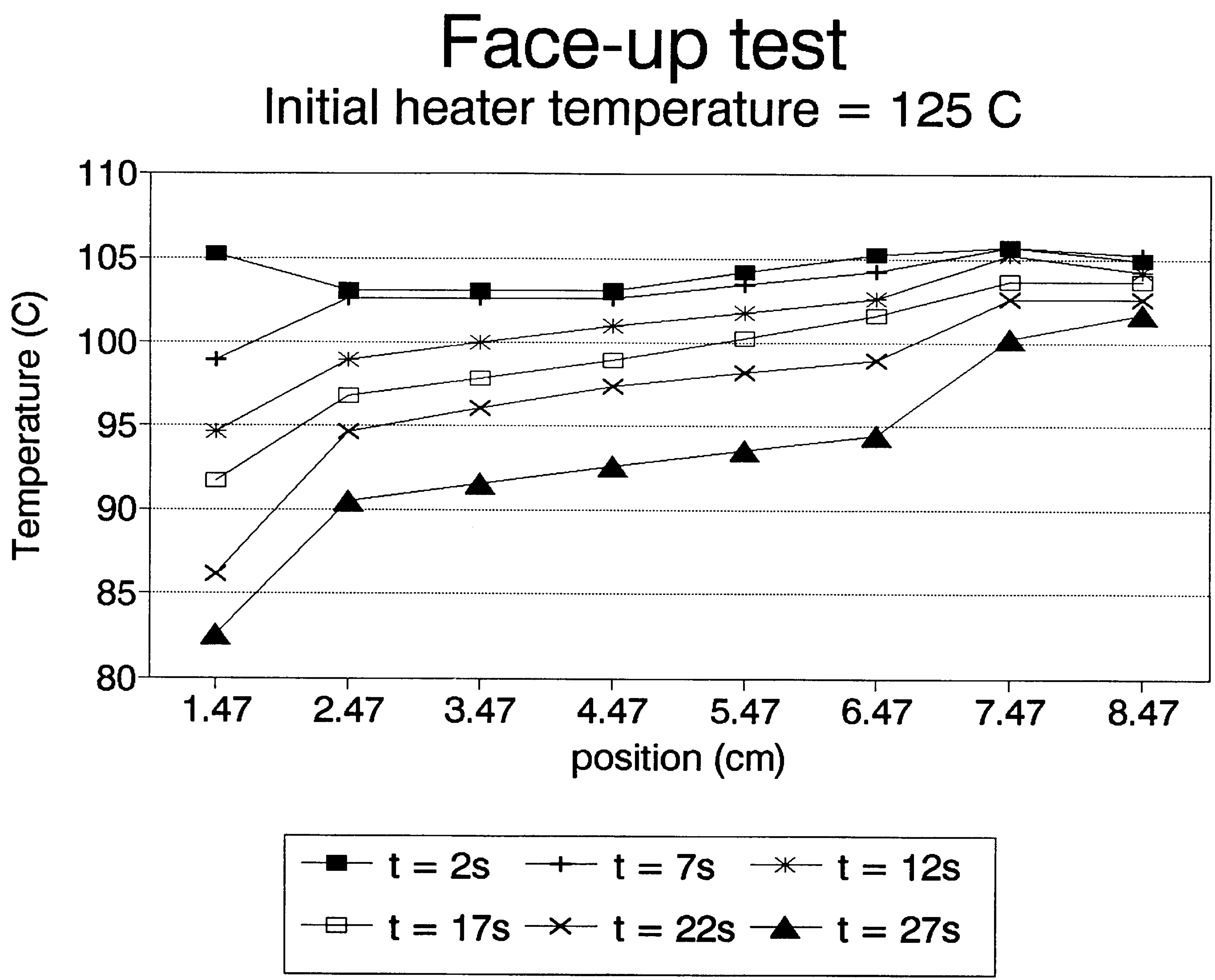



Face-down test
Initial heater temperature = 145 C
Temperature (C)
125
120
115
110
105
100
95
90
85
80
75
1.47
2.47
3.47
4.47
5.47
6.47
7.47
8.47
position (cm)
t = 28s
t = 30s
t = 33s
t = 36s
t = 39s
t = 0s

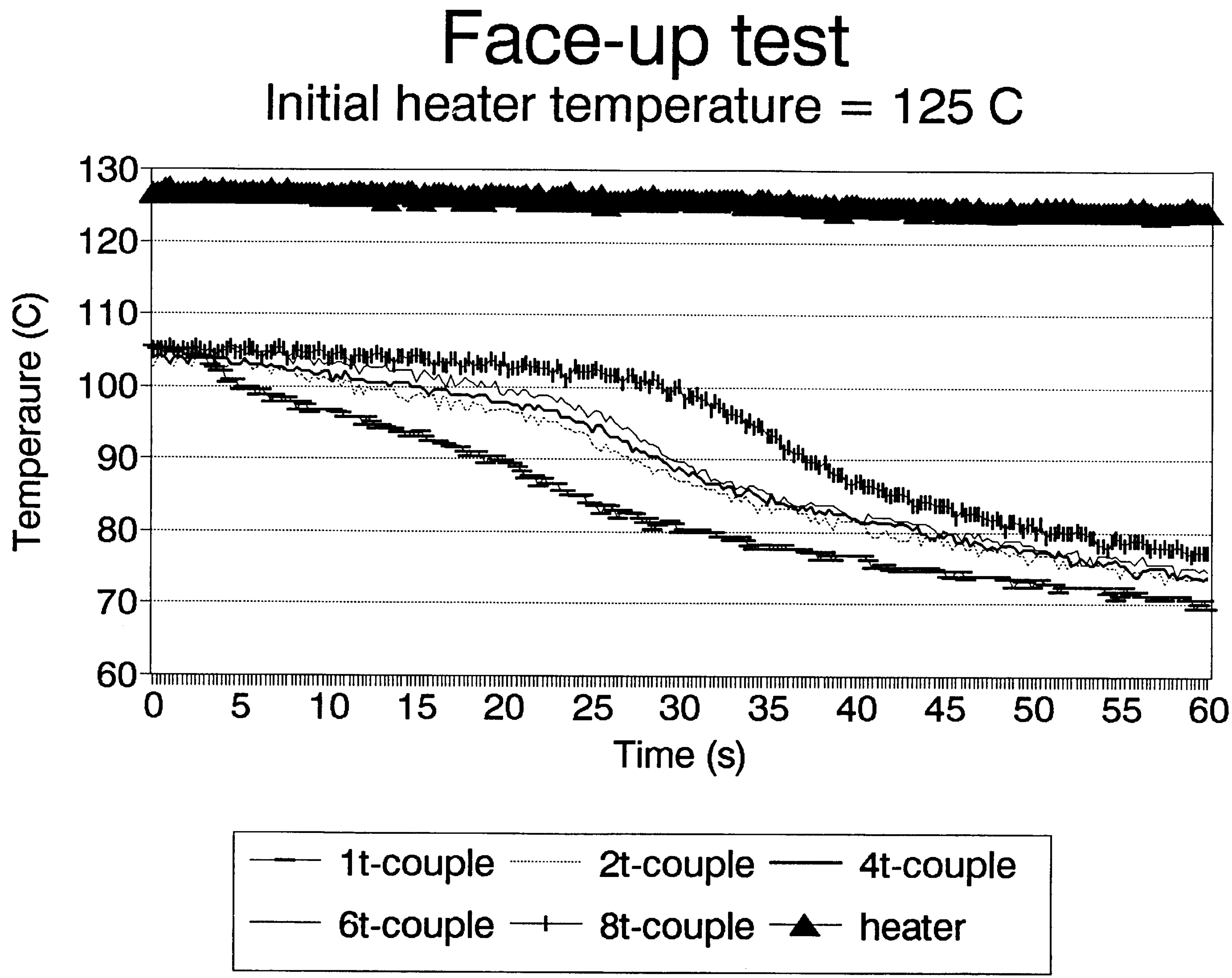
Face-down test

Initial heater temperature = 145 C



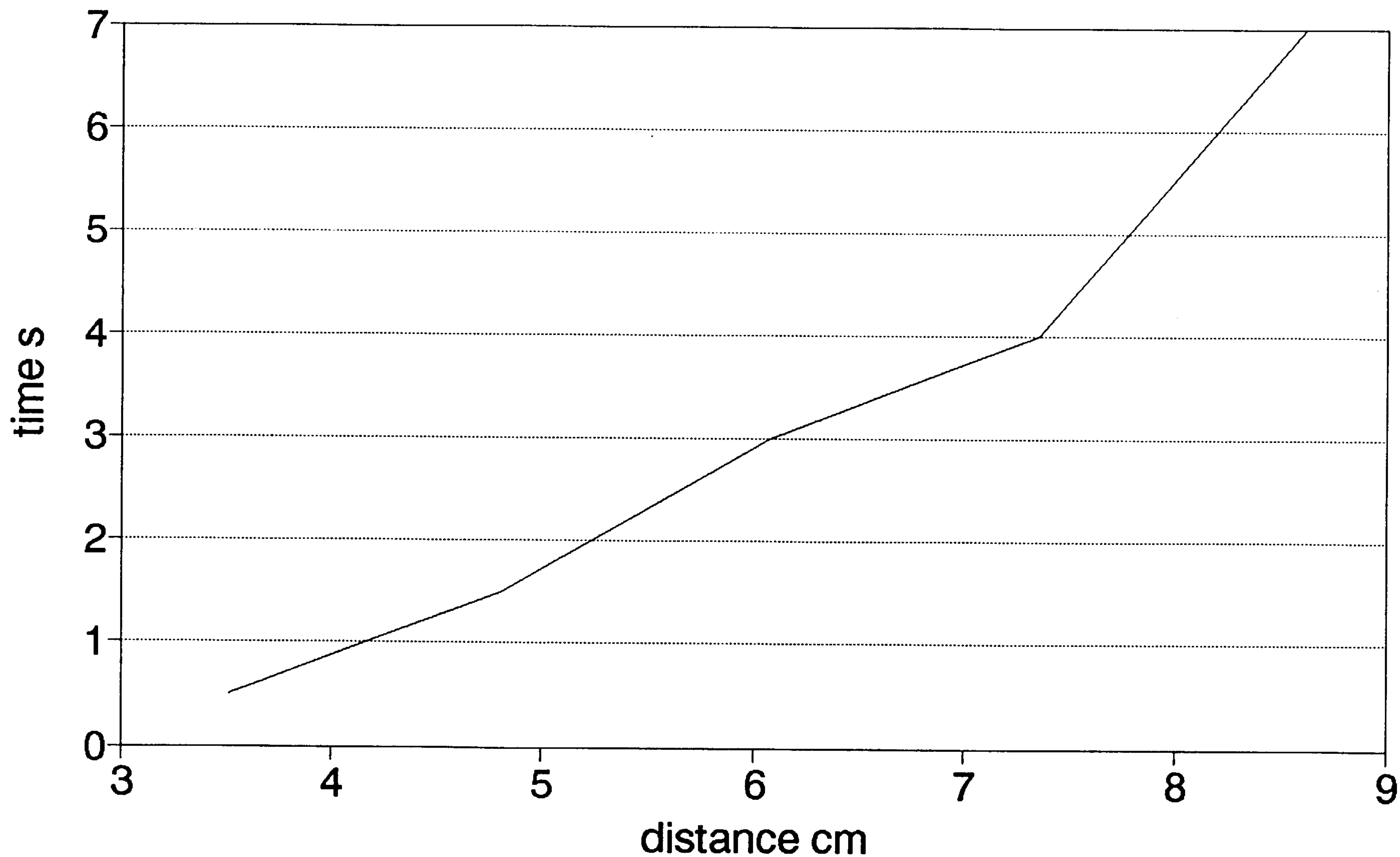


Face-up test
Initial heater temperature = 125 C
110
105
100
95
90
85
80
Temperature (C)
1.47
2.47
3.47
4.47
5.47
6.47
7.47
8.47
position (cm)
t = 2s
t = 7s
t = 12s
t = 17s
t = 22s
t = 27s



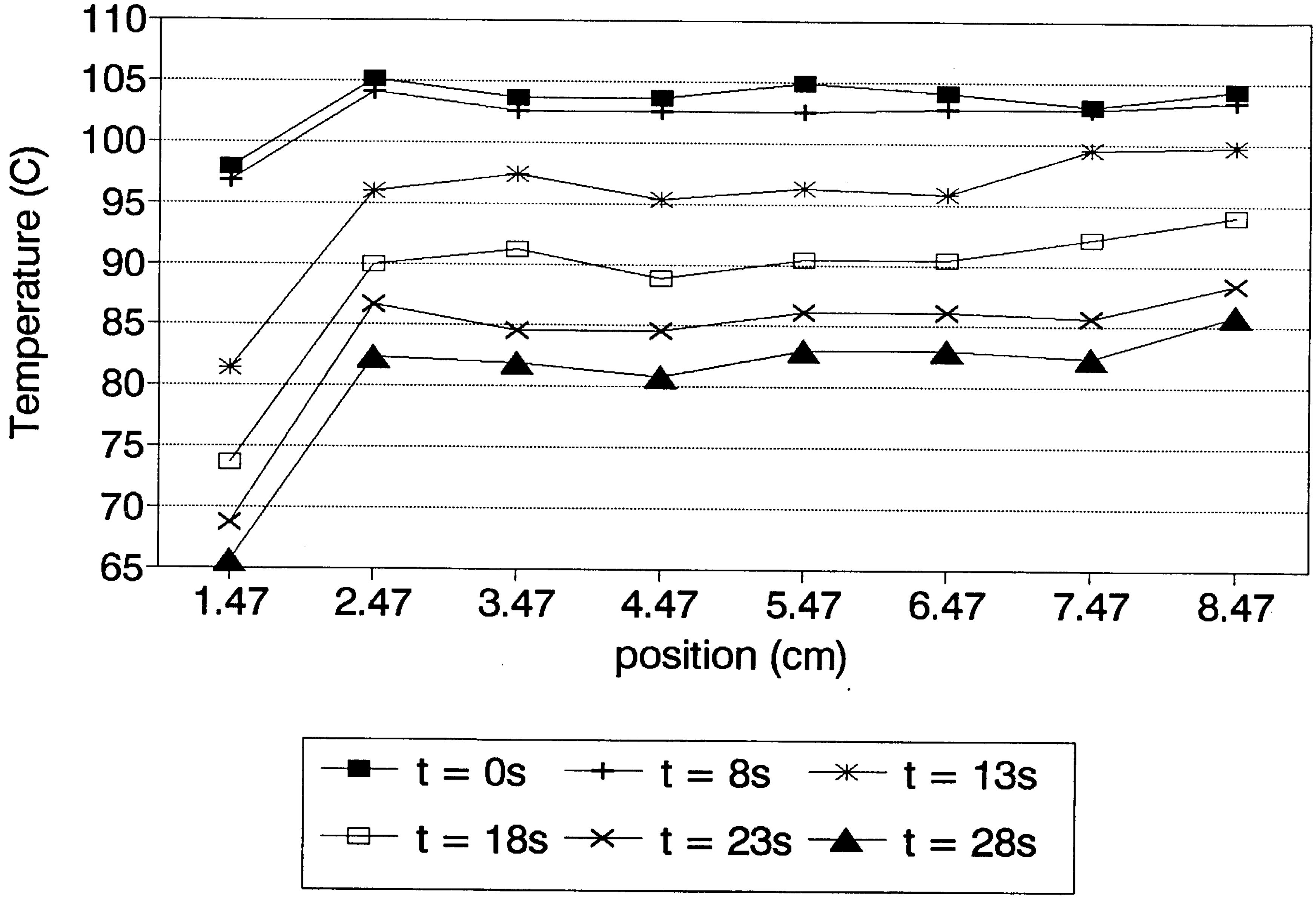
Face-up test
Initial heater temperature = 125 C
Temperaure (C)
130
120
110
100
90
80
70
60
0
5
10
15
20
25
30
35
40
45
50
55
60
Time (s)
1t-couple
2t-couple
4t-couple
6t-couple
8t-couple
heater

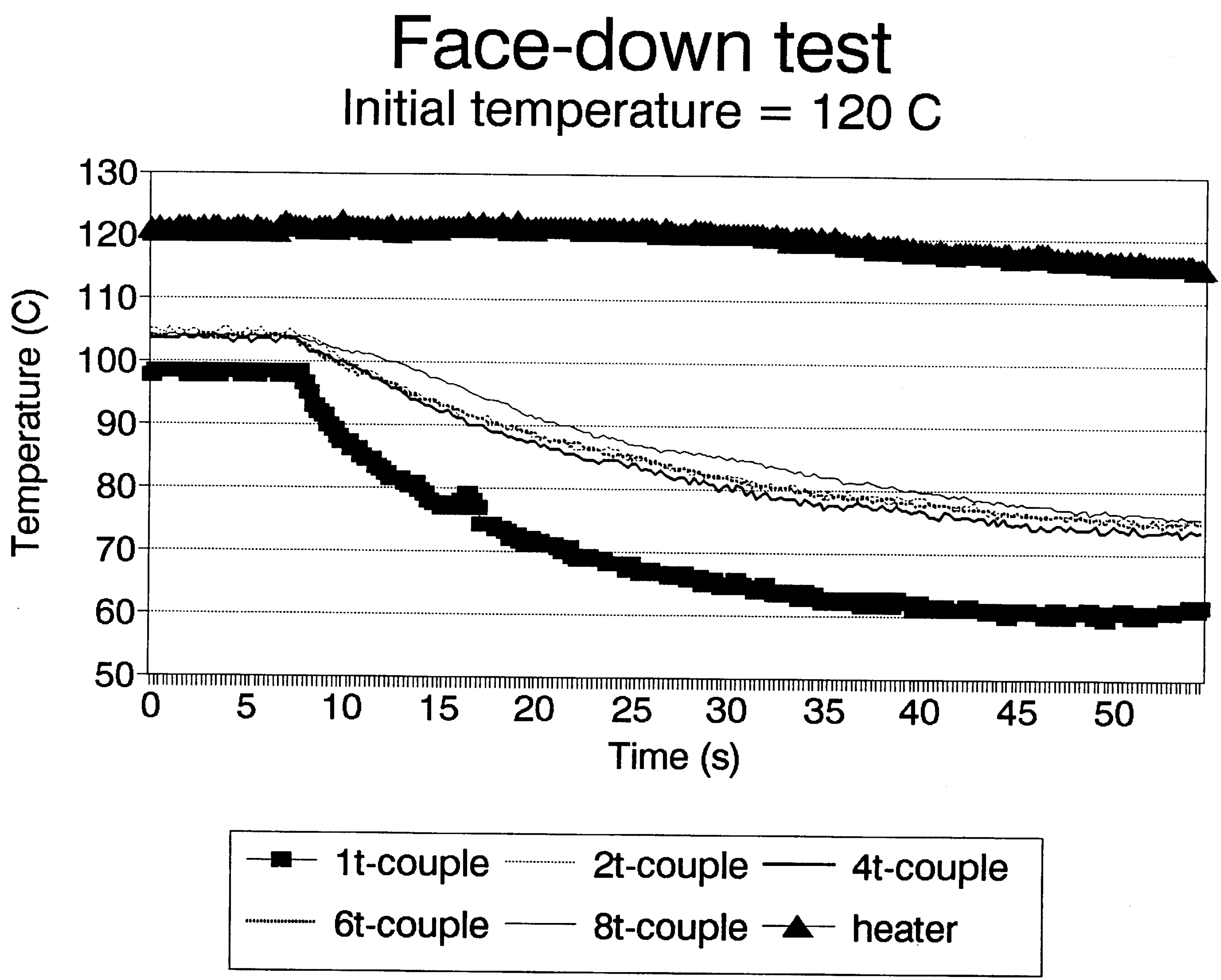
125 C
face-up



Face-down test

Initial heater temperature = 120 C




Face-down test
Initial temperature = 120 C
Temperature (C)
130
120
110
100
90
80
70
60
50
0
5
10
15
20
25
30
35
40
45
50
Time (s)
1t-couple
2t-couple
4t-couple
6t-couple
8t-couple
heater

REFERENCES

[1] Tien, C.L., Yao, L.S. Analysis of Conduction-Controlled Rewetting of a Vertical Surface. Journal of Heat Transfer, pp. 161-165, May 1975.

[2] Ungar, Eugene K. Saturated Pool and Flow Boiling from Horizontal Cylinders. Ph.D. Thesis pp. 71, University of Houston, August 1987.

[3] Chan, S.H., Zhang, W. Rewetting Theory and the Dryout Heat Flux of Smooth and Grooved Plates With a Uniform Heating. 1992 ASME Winter annual meeting, Anaheim, CA, November 8-13 1992.